# *STUDIES FOR STUDENTS*

## THE RECENT ADVANCE IN SEISMOLOGY

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### I. THE DISTRIBUTION OF SEISMICITY IN RELATION TO THE EARTH'S MOBILE BELTS

*Introduction.*—It is entirely safe to say that no period of equal length has registered so great an advance in the science of seismology as the decade now just brought to a close. The more important developments of this period may be broadly stated under three heads: (1) the determination of the laws of distribution of seismicity; (2) the discovery of a method for sensing and locating macroseisms through the body of the planet; and (3) the accumulation of so large a body of observational data as to advance from the condition of vague speculation to a well-grounded theory of the cause of earthquakes.

The laws of distribution of seismicity have been determined by a French officer of artillery, Count de Montessus de Ballore, whose thorough and conscientious work has occupied almost a lifetime. Rudolph had already, in 1887, made a most important contribution to the subject in a series of papers upon the distribution of seaquakes and submarine volcanic eruptions, which are supplementary to the studies by de Montessus. The discovery of new methods for studying at a distance the greater world-shakings is to be attributed, perhaps more than to anyone else, to the veteran English seismologist, Professor John Milne, who first started the great movement in Japan for seismological investigation, and since his return to England has been generously supported by the British Association for the Advancement of Science. The most modern and thoroughly equipped earthquake station today is, however, the German Chief Station for Earthquake Investigation at Strassburg, long directed by Professor Gerland, the founder of the International Seismological Association and the editor of its admirable

journal, *Gerland's Beiträge zur Geophysik*, in which appears the great annual catalogue of earthquakes.

The solid basis for the modern theory of causation of earthquakes must be credited in largest measure to the Austrian and Japanese schools of seismologists, though many outside these schools have made valuable contributions. Nowhere else in the world has earthquake investigation been carried to the same degree of well-planned refinement as in Japan, and nowhere is there a greater practical need for it. An admirable summary of Japanese achievements along this line is to be found in the recent work issued by the chairman of the famous Earthquake Investigation Committee.[1]

*The distribution of seismicity.*—The scientific investigations to determine the distribution of seismicity over the *land surface* of the globe may be said to have begun with the compilation of earthquake catalogues. The great catalogue of Perrey,[2] which fills six volumes, was a work which engaged an entire lifetime, and, full of errors as it is, has been the starting-point of all later work. More recently special catalogues have been prepared for particular seismic provinces; such, for example, as those of Milne for Japan,[3] Hoernes for Steiermark,[4] and Baratta for Italy.[5] It has remained for Count de Montessus de Ballore to devote the better part of his lifetime to collecting the scattered material now finally made available and by a process of correlation and standardization to lay the foundations for a new branch of the science—*seismic geography*.

The vast proportions of the work undertaken by the French savant above mentioned[6] will be appreciated when it is stated that the prob-

[1] D. Kikuchi, *Recent Seismological Investigation in Japan*, Pub. E. I. C. (foreign languages), No. 19 (1904), p. 120.

[2] Alexis Perrey, *Les tremblements de terre* (six volumes and a bibliography, Dijon, 1843–71).

[3] J. Milne, "A Catalogue of the Earthquakes Recorded in Japan between 1885 and 1892," *Trans. Seism. Soc. Japan*, Vol. IV (1895), pp. xxi+367, 2 pls.

[4] R. Hoernes, "Erdbeben und Stosslinien Steiermarks," *Mitth. d. Erdbeben-Kom. d. k. Akad. d. Wiss. z. Wien*, N. F., No. 7 (1902), pp. 1–115.

[5] M. Baratta, *I terremoti d'Italia* (Turin, 1901), pp. 960.

[6] F. de Montessus de Ballore, "Relation entre la rélief et la séismicité," *C. R. de l'Acad. des Sc. de Paris*, Vol. CXX (1895), pp. 1183–87.

——— "Introduction à un essai de description séismique du globe et mesure de la séismicité," *Beiträge zur Geophysik*, Vol. IV (1900), pp. 331–82.

——— "Loi générale de la repartition des régions séismiques instables à la sur-

lem which he set himself and carried to a most successful conclusion has been nothing less than the critical examination and cataloguing of all well-authenticated records of earthquakes to determine by a numerical figure the relative seismicity[1] upon a uniform scale of each earthquake province upon the globe; to prepare a composite map of epicenters for each; and, this once accomplished, to examine the topography and geology of each district with relation to its seismicity. No less than 170,000 separate shocks have thus been studied and placed in correspondence with each other.

His catalogue completed, de Montessus' first effort was to determine the relation of areas of high seismicity to the topographic relief. As a result, it is found that the seismic areas are throughout those of steepest general slope:

> In general, one may say that of two contiguous regions—for example, the two sides of a valley, the two flanks of a mountain chain, or plains and neighboring heights—the more unstable is that which presents the greater average slope, or the greater difference in altitude—that is to say, the greater relief either relative or absolute. The reason for this is without doubt that the relief is most frequently in consequence of the importance of dislocations; which, be it because of their lack of equilibrium, or because of the continuation of the tectonic movements which have caused them, quite naturally bring about earthquakes more easily.

The greater number of earthquakes, however, originate beneath the sea, and here, similarly, on the steep margins of the great oceanic deeps. For example, the scarp on the border of the great Tuscarora Deep has been the seat of much the larger number of destructive Japanese earthquakes. The vital question of the relation of earthquakes to volcanic activity, a dependence upon which was a quarter of a century ago the almost universal belief of geologists, is thus answered:

> Finally, while we may cite regions frequently shaken by earthquakes which at the same time have very active volcanoes, one should recognize the fact that

face du globe," *Berichte d. IIten international. Konferenz zu Strassburg, Beiträge zur Geophysik*, Ergänzungsband 2, 1903, pp. 325–34.

——— "Sur l'existence de deux grands cercles d'instabilité séismique maxima," *C. R. de l'Acad. des Sc. de Paris*, Vol. CXXXVI (1903), pp. 1707–9.

——— *Les tremblements de terre: Géographie séismologique;* avec une préface par M. A. de Lapparant; pp. v+475, 99 maps and figures, and 3 plates (Paris, 1906).

A brief account of the work of de Montessus and a list of his papers is given by F. M. Bernard ("Erdbeben Studien des Grafen de Montessus de Ballore," *Die Erdbebenwarte*, 1902, pp. 1–9).

[1] This term here implies both frequency and intensity of seismic shocks.


2.5
3
2.2
16
14
12

FIG. 1


Continent
Nord - Atlantique
Geosynclinal
Geosynclinal alpin
Continent
pacifique
circumpacifique
Continent
hypothetique
Africano - bresilien
Geosynclinal circumpacifique

FIG. 2

*there is independence of the seismicity and volcanicity* . . . . There is coincidence between the unstable regions and eruptions. . . . . But one phenomenon does not in a marked degree cause the other. This last negative law, which clearly results from the statistical researches, requires, however, a more detailed study. From all this we may conclude that, in general, earthquakes are a phenomenon purely geological, and that quite certainly they have their origin in dynamic causes by the effect of which the actual relief of the land is produced and of which they are the ultimate manifestation.

This conclusion of de Montessus is in harmony with that of Milne, who by an analysis of 10,000 earthquake observations in Japan showed that there were comparatively few which had their origin near to the volcanoes of the country.

As regards the broad distribution of the unstable areas upon the globe a most important law is discovered:

*The earth's crust quakes in nearly equal amount and in a unique manner along two narrow zones which are disposed on two great circles* (in the geometrical sense of the word), *which include between them an angle of about* 67 *degrees—the Mediterranean-Alps-Caucasus-Himalaya circle* (53.54 *per cent. of the shocks*) *and the circumpacific or Andes-Japan-Malay circle* (41.05 *per cent. of the shocks*). *These two zones coincide with the two most important lines of relief of the terrestrial surface. . . . . The zones including the seismic regions coincide exactly with the geosynclinals of the secondary era*, as they have been charted by Haug in his well-known work, *Les géosinclinaux et les aires continentales. The geosynclinals (the most mobile zones of the earth's surface) where the sediments have been deposited in greatest thicknesses, have been energetically folded, dislocated, and re-elevated in the Tertiary period at the time of the formation of the principal actual ranges (or geoanticlinals); and include in themselves, with two or three doubtful exceptions, all the seismic regions* (in the sense which we have given to these two words) *which, in consequence, characterize them.*

Fig. 1, which has been reproduced with additional data from de Montessus' maps, indicates the position of the geosynclinals between the continental areas, and in black the seismic areas. De Montessus' latest work, from which these plates and the above extracts have been taken, has recently issued from the press.[1] This work is devoted to the study of the geological structure of the unstable regions of the globe, and follows as a natural sequel to the completed catalogue of seisms by the same author. The soul of the work, as he frankly admits, is to be found in the generalizations of Bertrand, de Lapparant,

[1] F. de Montessus de Ballore, *Les tremblements de terre: Géographie séismologique;* with a preface by M. A de Lapparant (Paris, 1906).

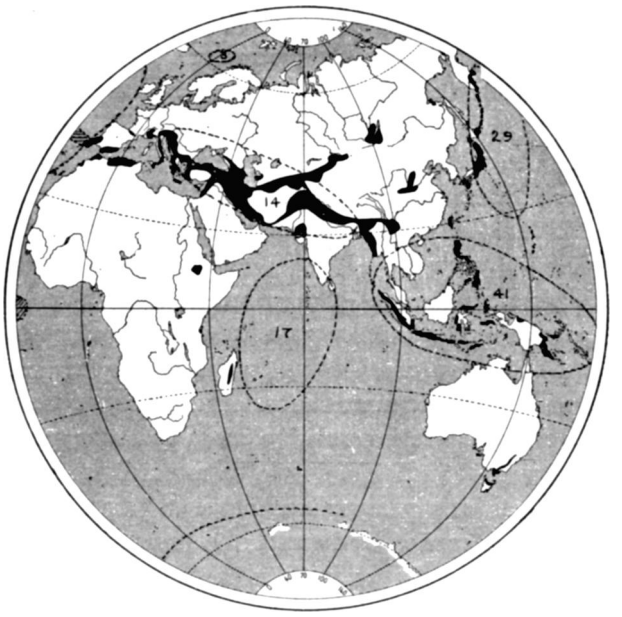
29
14
41
17

FIG. 3


Continent
Nord - Atlantique
Continent
sino -
sibérien
Continent
pacifique
hypothétique
Continent
Africano - brésilien
Continent
Australo - indo - malgache

FIG. 4

de Launay, and Suess; but the book is far more than a perfunctory comparison. It is only necessary to examine with care a few chapters to see that the author has given to each province conscientious study and has brought to his aid the latest researches of individual workers whose papers are not included in the generalizations of his predecessors. It is enough to say that the new volume constitutes a masterly work to which the future generation of geologists will find it necessary often to refer.

*The earth's mobile zones.*—The generalization of de Montessus, that the areas of high seismicity upon the earth's surface correspond in position to the geosynclinals as mapped by Haug,[1] makes it necessary that the valuable contribution of this savant be examined carefully. Wholly apart from this relationship, however, the paper is of great interest in itself, and should be especially so to Americans.

The conception of a geosynclinal is due to James Hall,[2] though the name was first applied by Dana,[3] who ascribed its folded structure to lateral compression, and not to the weight of the sediments, as did Hall. According to Hall, an enormous accumulation of sediments has followed certain zones of the earth's surface through gradual depression of the sea-floor along these belts; his law being that *the line of greatest depression coincides with the line of greatest accumulation*, a proportion being thus established at each point between the thickness of sediments and the amount of depression. The mountain chains form over the geosynclinals, a classical example being furnished by the Appalachian system. These generalizations Suess has supplemented by showing that within the folded regions the sedimentary series is generally complete and has a certain pelagic character, whereas in the unfolded districts one finds lacunae and intercalations of brackish water deposits.[4]

While Hall insisted that most of the sediments of the geosynclinals had their origin in shallow water, Suess referred to them as having a certain pelagic, and Neumayr even an abyssal, character. Haug's

[1] Emile Haug, "Les géosynclinaux et les aires continentales," *Bull. Soc. géol. France*, 3 Ser., Vol. XXVIII (1900), pp. 617–711.

[2] James Hall, *Nat. Hist. of New York: Paleontology*, Vol. III, p. 70 (Albany, 1859).

[3] J. D. Dana, *Manual of Geology* (2d ed., 1875), p. 748.

[4] Ed. Suess, *Die Entstehung der Alpen* (1875), p. 98.

view is that these sediments were deposited in a depth between that of the shallows and that of the deep sea (more definitely between depths of 80–100 and 900 meters)—a zone to which he has applied the name *bathyal*. Within this zone the geological rock formations are chiefly shales, clays, marls, schists, and compact and nodular limestones; and Haug finds a strong analogy between the distribution of fossils in rocks of this class which were formed during the Secondary era and the distribution of living forms within the bathyal zone of the ocean.

Hall's theory, which regarded the sediments of the geosynclinals as having originated in shallow water, required a most perfect equilibrium to exist between the rate of depression and the rate of accumulation; provided the same lithologic character was to be maintained for great thicknesses; but this adjustment is less necessary if greater depths of the floor of deposition be assumed. Haug expresses the view that in the vast majority of cases a correspondence exists between the axes of folds subsequently developed in a geosynclinal and the axis of the geosynclinal itself, instancing many French examples.

It is, however, the geographical distribution of the geosynclinals and their relation in position to former continents, in which the original contribution of Haug chiefly consists:

> The American authors, to whom is due the notion of geosynclinal, have always taken as the point of departure of their orogenic theories the fundamental idea that mountain chains form on the border of the oceans and that the continents increase by the addition of new chains successively more recent. According to this hypothesis, the geosynclinals should be born at the margin of the continents and the oceans, and should be exclusively of littoral sediments, and the zone of depression where the intensive sedimentation is going on should be separated from the high sea by a mere swell (*bourrelet*). It is easy to demonstrate that it is not under these conditions that the geosynclinals form; and that, far from originating at the margin of the oceans, they are always situated between two continental masses and constitute the mobile zones between masses relatively stable.[1]

As special cases in point the Himalayas and the mountain chains of central Europe are cited, and the general law is thus stated:

> (1) *The geosynclinals, the essentially mobile regions of the earth's crust, are always situated between two continental masses, the regions relatively stable;* (2) *the geosynclinals constituted before their filling marine depressions of a very considerable depth.*[2]

[1] *Loc. cit.*, p. 630. [2] *Ibid.*, p. 632.

After a discussion of the geosynclinals of the different geologic periods, it is added:

> Thus follows, even into the details, the conformity of the geologic history of the regions which have been affected by the large foldings of the Tertiary epoch, with those which have been occupied by the geosynclinals during all the Secondary era. If, in certain cases, one finds that the sinuosities described by the geosynclinals have not always been the same during two consecutive epochs, it is none the less true that they are always the same large regions which, since the beginning of Primary time, have been the mobile portions of the earth's crust.[1]

As regards, now the continents which have been separated by the geosynclinals, Haug states:

> It results from the summary given that zoögeographic works in all points confirm the conclusions relative to the existence of ancient continents quite different from the actual ones—conclusions obtained before by purely geological considerations. By a series of deductions borrowed from zoögeography we are led to admit the former existence of a *North Atlantic Continent*, of a *Sino-Siberian Continent*, of an *Australo-Indo-Malay Continent*, and of a *Pacific Continent*.[2]

Under the head of the breaking-up (*morcellement*) of the continents, Haug treats of this as having in some cases been accomplished by a gradual transgression of the sea; in other cases, by the production of vertical faults along which blocks of the crust have been depressed to produce abysses (the horsts remaining in relief); and in still other cases, by the depression of a continent in its entirety, so that a basin now occupies its former position, which is bounded by peripheral fractures marked out by volcanoes.

After an extensive study of stratigraphic documents with a view of fixing the positions of areas of transgression and recession of the sea, Haug argues that, if these are to be ascribed to the attraction of the glacial ice or to variations in the velocity of rotation of the planet, there should be alternations of transgression and recession between the polar and the equatorial regions, and also between the two hemispheres. He finds:

> (1) *The principal transgressions of the sea are produced simultaneously in the two continents.* (2) *They are produced simultaneously in the polar and equatorial regions.* (3) *They are not universal.*

[1] Ed. Suess, *Die Entstehung der Alpen*, p. 642.

[2] *Ibid.*, pp. 663, 664.

To these generalizations is added the positive one:

*Whenever a definite member of the sedimentary series is found in transgression upon the continental areas, the same member will be in recession in the geosynclinals;*

and reciprocally:

*Whenever a member is found in transgression within the geosynclinals, it will be in recession upon the continental areas.*[1]

It should be understood that the views of Haug above expressed set forth the attitude of a particular school of geologists; which views are opposed, as the quotations from Haug indicate, by those geologists who accept the doctrine of continental permanence.

[1] *Ibid.*, p. 682.